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A General Method for Routing Fibers in the ATLAS TileCal

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ABSTRACT

A general solution to the routing of the WLS fibers to PMT's in the ATLAS TileCal Detector is described. This scheme can be used to find the fiber lengths and the assignment of PMT's to readout cells which minimizes the fiber length and optimizes the uniformity of light yield within the cell and between cells. It should work for any choice of depth segmentation and for barrel as well as extended barrel modules.

1. Fiber Routing Requirements

The ATLAS TilCal detector utilizes wavelength shifting (WLS) fibers to transmit light from the scintillating tiles to photo-multiplier tubes (PMTs). The WLS fibers have an attenuation length of about 2 m for the yellow-green light which is the primary wavelength being transmitted. To maximize the amount of light reaching the PMTs, the WLS fibers should be as short as practical. However, studies have shown[1] that using the same length for all fibers within a cell improves the energy resolution. A readout cell can include 100 or more fibers coming from a region as long as 1.2 m in the Z (axial) dimension, as shown in Fig. 1. The requirement for equal lengths means that the extra length for fibers coming from locations close to the PMT must be accommodated somewhere along its route. The only space available for this extra fiber length is in the region along the girder that forms the backbone of the module.

The readout cells form towers corresponding approximately to intervals in pseudo-rapidity (typically 0.1). Since the cells overlap in the Z dimension the fibers from these cells must cross each other enroute to the PMTs. To facilitate the installation, the fibers should be constrained to bundles which do not obstruct the routing of fibers from other cells. The fiber routes should also have curvature radii as large as possible to minimize any long term damage to the fibers.

The method used to install and route fibers in the barrel module0 was developed by the Lisbon group and is described in the Tilecal TDR and detailed in ATLAS Tilecal Notes[1-3]. In preparation for the construction of the extended barrel module0 in the US, we have studied these routing techniques to see how they apply to the cell structures that have been proposed for the extended barrel and to try out alternatives.

2. The TileCal Model Used at MSU

To pursue the fiber routing studies described above, we needed a three dimensional, full scale model of a TileCal module. Since we had a limited purpose, time and money, we decided to make a wooden model of the exterior of one side of a girder plus 20 cm of the master/spacer plate structure where the fibers pass into the girder space . The model, shown in Fig. 2, was about 2/3 of the length of an extended barrel module, long enough to have a complete set of fibers from overlapping depth segments, but small enough to be portable and fit on a lab bench.

We used 1 mm WLS fiber cut to appropriate lengths and held in place using small lengths of plastic 'profile' pressed into slots to simulate the way fibers enter the girder region. Care was taken in cutting these slots to avoid cumulative errors in the spacing. Instead of the plastic 'rulers' used to constrain the fibers where they leave the profiles, we used a strip of cardboard cut against the grain, passing the fibers through the holes formed by the corrugated interior layer.

3. The Routing Scheme

One of the techniques that the Lisbon group developed was to collect the fibers from a readout cell into a few bundles. The bundles were constrained to pass through loops that were placed along the desired route. Some of their loops were free to slide along a rod mounted on the surface of the girder and parallel to its length. Loops could be added to the rod and positioned as needed.

We used a variation of this technique. Loops (made from plastic cable ties) were placed in a regular pattern on the surface of the girder, midway between each pair of PMT locations and also above and below each PMT, as shown in Fig. 2. The loops along the middle of the girder (between PMTs) were oriented so the fibers passed through them in the 'up/down' direction, while the loops along the girder edges directed the fibers parallel to the length of the girder.

We collected the fibers into sub-bundles consisting of the set of fibers in the interval between PMTs that were going to the same destination. These sub-bundles typically contained 16 fibers, but could contain fewer if a cell boundary fell in that interval. The fibers in these small bundles were registered so that their ends were even and then were held together with a small rubber band. The small differences in the distances from the points where fibers leave the 'ruler' to the end of these bundles can easily be absorbed in the twists and turns along the route. The bundles are each routed independently to their destination PMT, but are constrained to pass through every loop along their path. This simplifies the handling of the fibers and guarantees that the fiber routes will not interfere with each other or with the access to the PMT entry tube.

With these constraints, all fiber routes are well defined and can be studied in a systematic way. We note the following characteristics, illustrated in Fig. 3.

- The bundles enter the route through the loop at the bottom of the girder, below the PMT either to the right or left of their entry interval, illustrated in Fig. 3a. The distance required for this entering turn is a constant, 235 mm.
- The bundles can exit their route (enter the PMT location) in two possible ways as shown in Fig. 3b. The can either start the exit turn from the loop below the neighboring PMT or start the turn from the loop below the exit location. The first type of turn has a radius of 60 mm, while the second requires a smaller turning radius of 45 mm. Both types of turn take the same length of fiber, about 190 mm. (The figure doesn't accurately show the length in 3 dimensions.) The bundles of fibers will have to be withdrawn from the PMT entry hole to check the routing with a light and to make sure they are all flush with the bottom of the bundle tube before gluing. This is only possible if all of the fiber bundles enter from below.
- There are three mid-route possibilities shown in Fig. 3c. The bundle of fibers can proceed straight ahead to the next loop (J), change from the lower to upper row of loops, or vice-versa, without changing direction (S), or change direction and row (U). The fiber length between loops is approximately the same for each of these maneuvers. Since the S and U maneuvers go through an extra loop they require twice as much fiber length compared to J.

The length of fiber in all of the bundles going to the same destination can be made equal by inserting some combination of J, S and U steps in the route. A route can be described using a system of 4 coordinates designated (a, b, y, c), where

a = 1, for the upper row of loops
a = -1, for the lower row of loops,

b = 1, if the bundle is transporting light toward the right
b = -1, if the bundle is transporting light toward the left,

y = horizontal position along the girder (positive sense to the right)

c = cumulative path length (in units of PMT spacing),.

The steps J, S, and U can then be treated as operators that change the coordinates:

$J(a, b, y, c) = (a, b, y+b, c+1)$
$S(a, b, y, c) = (-a, b, y+b, c+2)$
$U(a, b, y, c) = (-a,-b, y, c+2)$

A computer program was written to search for the minimum common length for all bundles from any size cell routed to any PMT location. We find that requiring exit Mode 1, with the larger radius of curvature, requires about 100-500 mm extra fiber length compared to the scheme which allows exit Mode 2. Since this costs about 25% additional loss of light, we will assume that the routing schemes which include Mode 2 will be preferred. The results are summarized Table 1 which lists the minimum common lengths of the fibers from the point where they leave the 'ruler' to the end that will be polished in the girder ring. The rows in the table corresponds to the number of PMT's between the entry and destination of the bundle. This table includes all possible cases up to the largest cells foreseen in the extended barrel modules.

For example, if a cell had 7 bundles of fibers, and the fibers were routed to a PMT located as close to the middle of the cell as possible, the farthest bundle entry would be routed past 3 PMT's before reaching its destination PMT. The minimum common fiber length in this case is 889 mm. The routing for the furthest bundle is listed as T-S-S-1, meaning that the bundle it turned toward the destination PMT, makes two S maneuvers and inserted into the aspirin tube via Mode 1. The next closer bundles are routed T-S-S-2, etc.

Table 1. Routing Pattern vs. Relative Bundle Position*

Number of PMTs between the bundle entry and exit	Minimum Common Lengths		
	L_1 = 425 mm	L_2 = 889 mm	L_3 = 1005 mm
0	T-2	A-U-S-2	A-U-J-U-2
1	T-1	A-U-S-1	A-U-S-J-1
2	-	T-S-S-2	A-U-S-J-2
3	-	T-S-S-1	T-J-S-S-2
4	-	T-J-J-J-J-2	T-J-S-S-1
5	-	T-J-J-J-J-1	T-J-J-J-J-J-2
6	-	-	T-J-J-J-J-J-1

*Notation:
T => Bundle entry turns toward destination PMT
A => Bundle entry turns away from destination PMT
1 => Bundle exits to PMT via Mode 1
2 => Bundle exits to PMT via Mode 2

Notice that for fiber bundles which start at a distance of 2 or 3 PMTs away from their destination, the bundle never follows the most direct route containing only J type steps between the entry and exit. This means that for readout cells containing 5, 6, 7 or 8 bundles, this routing scheme requires fiber lengths that are about 230 mm longer that the lengths defined by the direct path of the farthest fiber.

4. Results Applied to the Extended Barrel.

This routing scheme has been applied to the cell structure which will be used for the extended barrel module 0 as shown in Fig.1. Table 2 lists some of the details of the fiber routing for this cell geometry. The PMTs are numbered starting with 1 for the PMT nearest the gap. PMT assignments have been chosen to optimize the routing of the inner depth segment. The same PMT assignments are made on both sides (R and L) of the module. PMT positions 1 and 5 have been reserved for the ITC and crack scintillators. Submodules are numbered starting with 0 for the ITC, and with the short submodule as number 8. The tile positions are numbered from 0-31 for the normal submodules, 0-21 for the short one and 0-9, 0-33 for the two ITC sections. Fiber lengths are computed as the sum of the routing lengths taken from Table 1 added to the length of fiber required to reach the tiles. An extra 1 cm is added for all but the innermost layer to allow some tolerance in the overlap of the fiber on the tile.

Table 2. Fiber Routing Applied to the Extended Barrel Module with the 3-4-4 cell geometry

EB Mod0 Cell	Submodule-Half Period* first tile	last tile	Number of fibers per side	PMT #	No. of Bundles R (L)	Fiber Length (cm) long	short	Rout-ing list
A12	1-0	1-18	19	4	2 (3)	207	198	L_1
A13	1-19	3-4	50	6	5 (5)	253	244	L_2
A14	3-5	4-27	55	10	5 (5)	253	244	L_2
A15	4-28	6-23	60	15	6 (6)	253	244	L_2
A16	6-24	9-31	94	21	9 (8)	253	244	L_2
B11	1-0	2-0	33	7	3 (4)	224	211	L_2
B12	2-1	3-22	54	8	5 (5)	224	211	L_2
B13	3-23	5-17	59	12	6 (6)	224	211	L_2
B14	5-18	7-17	64	17	6 (6)	224	211	L_2
B15	7-18	9-31	68	22	7 (6)	224	211	L_2
C9	0-0	0-9	10	3	1 (1)	139	124	L_1
D5	0-0	0-33	34	2	3 (3)	124	109	L_1
D6	1-0	4-31	128	9	12 (12)	170	155	L_2
D7	5-0	9-31	150	19	12 (12)	170	155	L_2

* Submodule 0 = ITC, submodule 8 = short one

5. Conclusions

The routing scheme described above can be applied to any cell structure in the Tilecal barrel and extended barrel modules. It has the advantage of being easy to implement by collecting the fibers into small bundles and then following a list of simple steps to bring that fiber bundle to the PMT. The routes are restricted so that there is minimal interference between bundles. In some cases these restrictions require that the routes be 23 cm longer than the most direct route.

References

[1] A. Gomes et al., “Routing of the Fibers in Module 0”; ATLAS TILECAL-NO-107, Jan. 1997

[2] A. Gomes et al., “Insertion of the Fibers in TileCal Module 0”; ATLAS TILECAL-NO-105, Jan. 1997

[2] A. Gomes et al., “Barrel Readout Cell Geometry (Module 0 Implementation)”; ATLAS TILECAL-NO-106, Jan. 1997